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Organic and Bio material Surface Modification via Corona Discharge induced Atmospheric-Cold Plasma

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Abstract

This paper is to elucidate on the cold plasma-mediated surface modification of organic cells and biomaterials. We demonstrate that the non-aggressive cold plasma can apply on organic materials without causing thermal and electrical damages. The atmospheric pressure cold plasma was generated by utilizing the combination of corona discharge-induced plasma on a tip edge, and the dielectric barrier discharge (DBD). Specifically, this work presents the transformation of the hydrophobic to the hydrophilic surface of sunflower seeds. Therefore, our cold plasma becomes an alternative method of surface treatment for the organic- and bio- materials.

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Keywords: Atmospheric Cold Plasma; Corona Discharge; Dielectric Barrier Discharge; Ozone, High Voltage

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The nature of corona discharge plasma involves with high electric field localized at the edge of associated electrodes. Corona induced plasmas are usually classified according to its gas temperature, non-thermal (cold) plasma, and thermal plasma. There are extensive studies on the applications of utilizing high electric fields in bio, solid and liquid organic materials [1-4]. In environmental applications, for example, the high-voltage electrical discharge has been employed in water cleaning and wastewater treatment [2]. In agriculture applications, many researches have been focused on modifying and improving seed germination characteristics. For enhancing the germination process, oxygen may be provided to seeds by using the chemical based water to improve the germination rate [3]. However, such traditional processes leave the chemical residual causing pollution to the environment. In contrast, the cold plasma is an environmentally friendly, and does not leave any contaminated aqueous waste. In this paper, we propose a cold plasma generated by employing the benefit of fringe field inducing corona discharge on tips' edges in conjunction with the dielectric barrier discharge (DBD) for seed surface modification. Our objectives are (1) to determine if organic materials, such as sunflower seed, used in this work, can survive under atmospheric cold plasma surface treatment without thermal damage, (2) to obtain better hydrophilic properties, leading to better water absorption and enhancing the rate of seed germination acceleration. The water droplet process and contact angle measurement were performed before and after treatment to substantiate the effectiveness of the surface activation. [5-7].

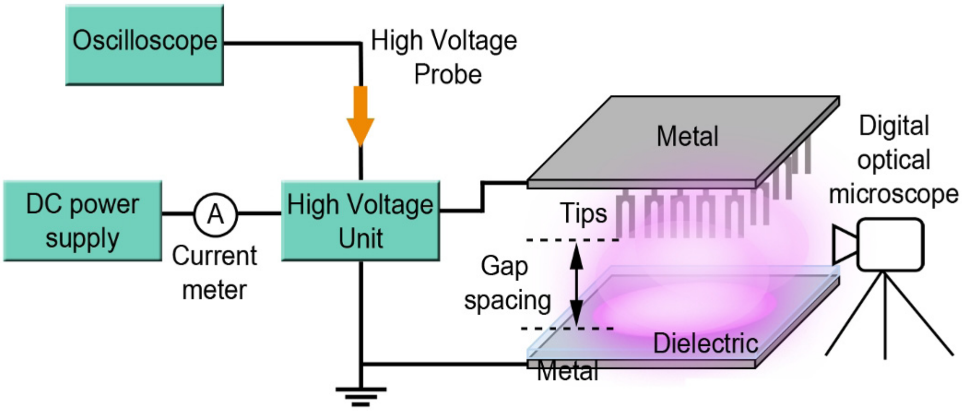

Fig. 1. Schematic Schematic diagram of the plasma device and the experimental setup

Fig. 1 demonstrates the schematic diagram of the cold plasma system utilized in this work. The DC power supply (OMRON DC 24V, 2.1 A) was connected to High Voltage Power Supply Generator. Under plasma operation, the average power consumption was ~5 W. The tips which are stainless steel tip with ~4 cm long and a pair of cut sharp edge, serve as the powered electrode, and a dielectric layer is placed covering a grounded metal plane electrode in order to prevent the transition from corona to arc, causing the thermal damage to bio-materials, and also to stabilize the atmospheric corona gas discharge plasma. Air is the main feed gas of the plasma generation. The argon (Ar) gas may, however, partially introduce to form a mixture of Ar/air.

During such treatment, active species such as charged particles, radicals and UV photons generated in plasma will react only with the surface of a material, leaving the bulk material unchanged. Therefore, to substantiate that our corona discharged-induced plasma is non-equilibrium plasma, the rice grain was exposed to glow discharge plasma. Thermal Imager (Fluke-Ti100) and Thermopoint (AGEMA Infrared Systems) were utilized to measure the real time temperature of operated sample (Fig. 2). During plasma operation, the surface temperature of the specimen increases less than 1°C, whereas high voltage pulse induced plasma in DBD structure shows ~6-13°C temperature increasing after ~1 min treatment [6]. Therefore, this method allows a gentle seed treatment due to the negligible increase in temperature. The studies of cold plasma treatment effects on the organic material surface were carried out with sunflower seeds instead of using rice grain due to larger surface area. The seeds were introduced into cold plasma chamber as shown in Fig. 2a to investigate the efficiency of the plasma treatment. Water droplet approach was the primary method to study the water absorption including the hydrophobic and hydrophilic surface. The contact angle measurement from water droplet method also demonstrated the activation of the surface.

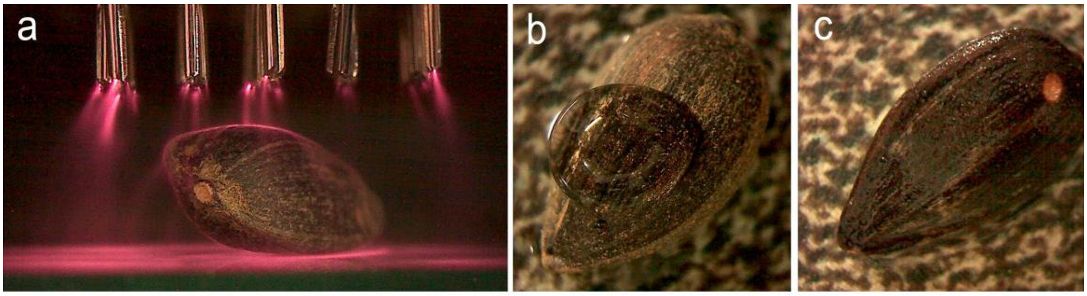

Fig. 2. Sunflower seed surface modification experiment. (a) Seed under plasma operation cold plasma generation. (b) 5 µl water droplet on the non-treated seed surface. (c) 5 µl water droplet on the treated seed surface.

Fig. 2a illustrates the performing of atmospheric plasma treatment on sunflower seed under air and the mixture of Ar/air ambient with the operation time of 1, 2 and 5 minutes. Water droplet (~5 µl) was performed on controlled (non-treated) and treated seeds to evaluate the wettability enhancement. The water droplet and the contact angle were performed right after plasma operation. The result shows that the non-treated sunflower seed surface is naturally hydrophobic (Fig. 2b) with very slow water absorption process (more than 20 min of 5 µl water droplet). On the other hand, the treated sample (with ~2 min and ~5 min under Ar/air and pure air ambient, respectively) shows better hydrophilic surface, and shorter water uptake time, which is less than 5 min (Fig 2c). Sample seeds were performed more than 50 seeds of each experiments to confirm the reliability of our experiments. Therefore, the overall result suggests that the wettability of the sunflower seed was improved significantly by the cold plasma treatment with appropriate conditions. In this work, the mixture of Ar/air ambient with treatment time ~1-2 minutes or pure air ~2-5 minutes enables hydrophilic properties of sunflower surface, allowing shorter time of water uptake process (only ~1-2 minutes). The non-treated sunflower seeds typically need more than ~15-20 minutes for completing the water uptake process. The reactive species in the gas discharge plasma activate the surface of the seed, enabling hydrophilic property on the surface manifests itself in a decrease of the contact angle of liquid drops laid onto the surface. As depicted in Fig. 4, for example, the contact angle was measured right after plasma treatment (~2 min of Ar/air ambient), the average contact angle decreases from about 90° before to 25° after treatment. The increasing of droplet diameter and the decreasing of the contact angle on treated sample are relatively fast and finally spreading all over the surface. The wettability of the sunflower seed is improved significantly, resulting in an increased water absorption capability of the seed.

Note that, it has been known that cold plasmas are affecting only the surface with ~10 nm depth. Therefore, the cold plasma technique does not affect the nutrient of seed. Although the germination acceleration test and the nutrient percentage has not been performed yet, the results suggest that cold plasma mediated hydrophilic surface has a potential to improve the seed germination rate and capacity, which are advantageous for many slow-to-germinate seeds. The preliminary investigations show promising effects of the plasma treatment on organic surface properties from hydrophobic to hydrophilic surface. This process enhances water absorption, enabling higher the germination acceleration rate. Moreover, atmospheric pressure cold plasma is suitable in the field of medical researches for living cells treatment. Our cold plasma approach demonstrates low cost and less power consumption than current plasma technology. However, many criteria in cold plasma applications, for instance, nutrient, gas ambient, design structure, etc., have to be verified in further researches before commercialization.

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